TRACKING SYSTEM FOR FLAT MOBILE ANTENNA

Field of the invention

The present invention relates to a tracking system for flat antenna with combined mechanical pointing for one axis and electronic beam steering for the other axis, which can be mounted on moving vehicles and platforms and which provides television, Internet and other communication signals, transmitted by satellites.

Prior art

In order to receive signals from satellite, the antenna mounted on a moving vehicle should keep its orientation, so that its beam to be always directed toward the satellite. For this purpose antennas with mechanical or/and electronic beam steering are required, which work under control of a tracking system, which reacts to the changes of orientation of the vehicle (or directly of the antenna) and issues commands to motors or to block for electronic beam control to provide necessary corrections in beam direction. In most cases such tracking systems include sensors for angular velocity (rate gyroscopes), based on quartz, piezo-electric or micro electro-mechanical (MEMS) technology. They feature a low price, but suffer by significant error, produced by temperature change, linear acceleration and other factors on their offset and scale factor. That's why a key element of different tracking systems, which use such sensors, are different methods for correction of antenna orientation and gyroscope errors, using the measured strength of received signal. Most widely used methods are those for mechanical scanning in a small area around the estimated direction towards the satellite and mono-pulse method.

US Pat. No. 6,191,734 discloses a system, which uses a combined mechanical control of azimuth of the beam and electronic beam steering on elevation using phase shifters. By using additional phase

shifters, beam tilting is obtained at small angles on both axes in order to achieve higher scanning rate. The disadvantage of the mentioned system is the requirement for additional phase shifters, which makes it more complex and expensive. Moreover, the tracking system does not perform an estimation of gyroscope errors, hence, the antenna may lose its direction shortly after the signal path is hidden by an obstacle.

US Pat. No. 5,900,836 describes an antenna with mechanical drive. Its tracking system commands rotating in a given direction while a decreasing of signal strength is registered, after which the direction of movement is reversed. At particular intervals the movements in both directions are averaged and they are used later for correction of gyroscope offset. Due to big latencies of mechanical driving system the averaging intervals of such system are relatively large, which means that gyroscope offset corrections follow with big delays. Moreover, such a system can be affected by signal fluctuations due to small obstacles which don't completely interrupt the signal, but only decrease its strength for a short time.

US Pat. No. 5,309,162 is provided for antenna system, where the control of the motor for every axis is performed using the phase difference between the signals, received by two antenna panels. This system does not use orientation sensors, that's why it cannot keep its orientation when the signal reception is interrupted by an obstacle.

Summary of the invention

An objective of the present invention is to provide a tracking system with low price, which keeps the antenna beam in the direction towards the selected satellite, regardless of the movement of the vehicle, where it is mounted. It is also desirable that the antenna orientation is kept even during temporary interruptions of the reception due to obstacles non-transparent to radio waves like buildings, trees, tunnels, bridges, hills, etc.

To achieve these and other advantages and in accordance with the purpose of the present invention the tracking system for flat mobile antenna comprises:

sensors for angular velocity (gyroscopes);

sensors, which measure the orientation of the antenna towards the vertical axis (inclinometers);

control block, which calculates needed corrections of the direction of antenna beam, depending on measurement from above-mentioned sensors;

at least one motor, which changes the antenna orientation;

driving electronics, which drive the motor/s in order to move the antenna in desired direction;

block for electronic beam steering;

power supply block, which converts the voltage from the electrical network of the vehicle into suitable values for providing power supply to all blocks of the system.

It is advisable to use three sensors for angular velocity, each one mounted in parallel to one of the axes of Cartesian coordinate system, fixed with the antenna panel.

It is advisable in this case to perform a forward coordinate transformation to obtain the necessary corrections of azimuth and elevation angle of antenna beam and reverse coordinate transformation for obtaining corrections of gyroscope offset.

In one particular variant of the tracking system the axes of two gyroscopes lay on the elevation plane while the axis of the third one is orthogonal to it.

It is advisable that the antenna panel is moved mechanically in a small angle at one axis of deflecting of antenna beam, while the antenna beam is positioned by electronic control at fixed positions on the other axis and the signal strength, measured in two or more positions in a close proximity to the direction toward the satellite is

used for calculation of corrections of gyroscope offsets and for adjusting the orientation of the antenna beam.

It is advisable in this case that the antenna beam is controlled in such a way, that it keeps staying for a longer period in the fixed position, which is closest to the direction towards the satellite, while it is switched to neighboring fixed positions for much shorter intervals, thus keeping the average signal strength as high as possible.

It is advisable to perform an additional compensation of offsets for gyroscopes, which axes are horizontal or close to horizontal plane.

One possible variant of implementing such compensation is to integrate for a given time interval the output value of any one of gyroscope sensors, which axes are horizontal or close to horizontal plane, and if the result is positive, the offset of the corresponding gyroscope is corrected in positive direction, but if the result is negative, the offset is corrected in negative direction.

Another possible variant of such compensation is to transform the output signals of both gyroscopes into angular velocity vectors, which lie on the horizontal plane, and which sectors are integrated to obtain the inclination angles of the axes of both gyroscopes, which angles are compared with output signals of two inclination sensors (inclinometers), measuring the inclination angles of axes of mentioned gyroscopes, and the result from this comparison is used to adjust the estimated offsets of mentioned gyroscopes.

The advantages of the tracking system according to the present invention are: using low-cost sensors, decreased impact of gyroscope errors on tracking error, improved speed of correction of gyroscope errors using measured strength of received signal in comparison with antennas with mechanical-only beam movement, improved average signal-to-noise ratio (SNR) due to longer periods when the antenna beam is kept close to direction toward the satellite.

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Brief description of the drawings

Fig. 1 is a block diagram of the tracking system according to the current invention;

Fig. 2 is a drawing, showing the orientation of gyroscopes in Cartesian coordinate system, fixed with the antenna panel;

Fig. 3 is an illustration of the orientation of inclination sensors toward axes of Cartesian coordinate system, fixed with the antenna panel and their projections on the horizontal plane;

Fig. 4 is a diagram, which illustrates angular velocity vectors, corresponding to axes of Cartesian coordinate system, fixed with the antenna panel;

Fig. 5 represents a variant of implementation of the control block of tracking system, according to present invention;

Fig. 6 is a block diagram of one variant of implementing the compensation of offset value of one of gyroscopes, which axis is close to horizontal plane;

Fig. 7 is a block diagram of another variant of implementing the compensation of offset value of gyroscopes, which axes are close to horizontal plane.

Detailed description of the preferred embodiment

One possible variant of implementation of tracking system according to the present invention is shown at **Fig. 1**. It comprises sensors for angular velocity (gyroscopes) **1**, inclination sensors **2**, control block **3**, driving block **4**, motor **7**, block for electronic beam control **5**, antenna panel with electronic beam steering **8**, down-converter **9**, directional coupler **10**, decoding block **11**, and RF detector **6**.

The outputs of gyroscope sensors **1** and outputs of inclination sensors **2** are fed to control block **3**, as well as the outputs of RF detector **6** and block for decoding of received signal **11** are. One of the

outputs of the control block **3** is fed to the input of the block for electronic beam control **5**, while the other output is fed to the input of the driving block **4**, which output is fed to the motor **7**, which moves the antenna panel **8**. The antenna panel **8** output is fed to the input of the down-converter **9**, which output is connected to inputs of RF detector **6** and the decoding block **11** through directional coupler **10**.

The angular velocity sensors could be solid-state gyroscopes, for example based on quartz, piezo-crystal, MEMS or another technology. They are fixed to antenna panel **8** and provide signals, which are proportional to its speed of rotation around particular axes. In the present embodiment are used three gyroscopes **1a**, **1b** and **1c**, (**Fig. 2**), which are co-linear with the axes of Cartesian coordinate system Oxyz, fixed to antenna panel **8**.

The inclination sensors **2** could be solid-state, liquid-based or devices, based on another principle,which allow electronic measuring of the inclination of antenna panel toward the horizontal plane. In the present variant two inclination sensors, **2a** and **2b**, are used, which are fixed to antenna panel **8**. It is also possible to use a two-axis sensor, which measures the inclination of two of antenna panel axes towards the horizontal plane (**Fig. 3**). It is desirable that these axes are the same as the axes of two of the gyroscopes **1a** and **1b**, as this simplifies the data processing by the control block.

Fig. 5 is a block diagram of the data processing, performed by the control block during satellite tracking. The output signal from gyroscope **1a** is fed to the first input of subtracting block **12**, to which second input the output signal from offset memory ω_{xo} **13 is fed**. The output signal from gyroscope **1b** is fed to the first input of subtracting block **14**, to which second input the output signal from offset memory ω_{yo} **15 is fed**. The output signal from gyroscope **1c** is fed to the first input of subtracting block **16**, to which second input the output signal from offset memory ω_{zo} **17 is fed**. The output signals from subtracting

blocks **12**, **14** and **16** are fed to the inputs of the block for forward coordinate transformation **18**. The first output of the block for forward coordinate transformation **18** is fed to the first input of adder **19**, which second input is fed to the output of scaling block **20**. The second output of the block for forward coordinate transformation **18** is fed to the first input of adder **21**, which second input is fed to the output of scaling block **22**. The output of adder **19** is fed to the input of integrator **23**, which output is fed to the first input of subtracting block **24**. The second input of subtracting block **24** is fed to the output of azimuth scanning block **25**. The output of subtracting block **24** is fed to the input of motor control block **26**, which output is fed to the input of driving block **4**. The output of adder **21** is fed to the input of integrator **27**, which output is fed to the input of beam selection block **28**. The output of beam selection block **28** is fed to the input of the block for electronic beam control **5**.

The signal from RF detector **6** is fed to the input of switch **29**, input of signal drop detector **30** and input of sign inverter block **31**. The first output of switch **29** is fed to the input of first beam memory **32**, while its second output is fed to the input of second beam memory **33**. The output of the first beam memory **32** is fed to the first input of computation block **34**, which second input is fed to the output of second beam memory **33**. The output of the computation block **34** is fed to the first output of subtracting block **35**, which second input is fed to the output of integrator **27**. The output of subtracting block **35** is fed to the first input of block for reverse coordinate transformation **36**.

The output of sign inverter block **31** is fed to the input of integrator **37**, which output is fed to the input of memory block **38**. The output of memory block **38** is fed to the second input of block for reverse coordinate transformation **36**. The first output of block for reverse coordinate transformation **36** is fed to the input of sign detection block **39**, which output is fed to the input of scaling block **40**. The second

output of block for reverse coordinate transformation **36** is fed to the input of sign detection block **41**, which output is fed to the input of scaling block **42**. The third output of block for reverse coordinate transformation **36** is fed to the input of sign detection block **43**, which output is fed to the input of scaling block **44**.

The output of scaling block **40** is fed to the second input of subtracting block **45**, which first input is fed to the output of offset memory ω_{x0} **13**. The output of subtracting block **45** is fed to the input of offset memory ω_{x0} **13**. The output of scaling block **42** is fed to the second input of subtracting block **46**, which first input is fed to the output of offset memory ω_{y0} **15**. The output of subtracting block **46** is fed to the input of offset memory ω_{y0} **15**. The output of scaling block **44** is fed to the second input of subtracting block **47**, which first input is fed to the output of offset memory ω_{z0} **17**. The output of subtracting block **47** is fed to the input of offset memory ω_{z0} **17**.

Fig. 6 presents a block diagram of one variant for additional compensation of one of gyroscopes **1a**, which axis is near to horizontal plane. A similar compensation is used for the second gyroscope **1b**. The output signal of gyroscope **1a** is fed to the first input of subtracting block **48**, which second input is fed to the output of offset memory ω_{x0} **13**. The output of subtracting block **48** is fed to the signal input of integrator **49**, which reset input is fed to the first output of timer block **50**. The output of integrator **49** is fed to the input of sign detector block **51**, which output is fed to the input of scaling block **52**. The output of scaling block **52** is fed to the signal input of switch **53**, which control input is fed to the second output of timer block **50**. The output of switch **53** is fed to the first input of adder **54**, which second input is fed to the output of offset memory ω_{x0} **13**. The output of adder **54** is fed to the input of offset memory ω_{x0} **13**.

Fig. 7 presents a block diagram of another variant for additional compensation of gyroscopes **1a** and **1b**, which axes are close to

horizontal plane. The output of gyroscope **1a** ω_x is fed to the first input of subtracting block **55**, which second input is fed to the output of offset memory ω_{x0} **13**. The output of subtracting block **55** is fed to the first input of the first block for coordinate transformation **56**, which second input is fed to the output of integrator **57**. The output of the first block for coordinate transformation **56** is fed to the first input of adder **58**, which second input is fed to the output of scaling block **59**. The output of adder **58** is fed to the input of integrator **60**. The first input of subtracting block **61** is fed to the output of inclinometer **2b**, while its second input is fed to the output of integrator **60**. The output of subtracting block **61** is fed to inputs of scaling blocks **59** and **62**. The first input of subtracting block **63** is fed to the output of offset memory ω_{x0} **13**, while its second input is fed to the output of scaling block **62**. The output of subtracting block **63** is fed to the input of offset memory ω_{x0} **13**.

The output of gyroscope **1b** ω_y is fed to the first input of subtracting block **64**, which second input is fed to the output of offset memory ω_{y0} **15**. The output of subtracting block **64** is fed to the first input of the second block for coordinate transformation **65**, which second input is fed to the output of integrator **60**. The output of the second block for coordinate transformation **65** is fed to the first input of adder **66**, which second input is fed to the output of scaling block **67**. The output of adder **66** is fed to the input of integrator **57**. The first input of subtracting block **68** is fed to the output of inclinometer **2a**, while its second input is fed to the output of integrator **57**. The output of subtracting block **68** is fed to inputs of scaling blocks **67** and **69**. The first input of subtracting block **70** is fed to the output of offset memory ω_{y0} **15**, while its second input is fed to the output of scaling block **69**. The output of subtracting block **70** is fed to the input of offset memory ω_{y0} **15**.

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The operation of the tracking system according to present invention is as follows:

The control block **3** operates in two modes – acquisition and tracking. During acquisition mode the motor **7** is commanded to rotate the antenna panel **8** around vertical axis with particular velocity. At the same time the block for electronic beam control **5** switches consecutively the antenna beams to cover the whole field of view of the antenna, while the RF detector **6** measures the strength of received signal. The described action continues until a local maximum of the signal strength is found. After that the decoding block **11** reads the identification data from the transport stream of received signal, which is compared with a defined value by the control block **3**. If the received data do not match the defined value, the control block **3** continues the acquisition mode. When the identification data match the internal value, the control block **3** enters tracking mode. In this mode the control block **3** uses the signals from gyroscope block **1** and RF detector **6** to calculate the changes in antenna panel orientation towards the satellite direction, and issues the necessary control signals to the driving block **4** and the block for electronic beam control **5** to keep the antenna beam always directed towards the satellite.

The detailed description of the operation is as follows:

The contents of the offset memory ω_{x0} **13** is subtracted from the signal value ω_x of the first gyroscope **1a**. The initial value, which is contained in the offset memory ω_{x0} **13** can be obtained by measurement of gyroscope signal during stand-still condition or can be read from a table, prepared in advance, which defines the temperature dependence of the offset of particular gyroscope. The same operation is performed for output signals ω_y and ω_z of gyroscopes **1b** and **1c**. The resultant compensated signals correspond to angular velocities of antenna panel towards the three axes of Cartesian coordinate system $Oxyz$ (**Fig. 4**), which are labeled as ω'_x, ω'_y and ω'_z. These three values

are converted by the block for forward coordinate transformation **18** into angular velocities, collinear to axes of the coordinate system $Oxsz$, where s is a vector, pointing towards the satellite. As a result both angular velocities on elevation axis ω_θ and on azimuth axis ω_φ are obtained. By their integration by integrators **23** and **27** the deflection angles between the direction to the satellite and antenna panel axes by azimuth φ and by elevation θ are obtained. The azimuth scanning block **25** produces a sine signal with small amplitude and low frequency, which is subtracted from azimuth angle φ. The resultant difference signal is processed by the motor control block **26** in such a way, that the azimuth angle φ is kept approximately equal to the output signal of azimuth scanning block **25**. As a result the motor **7** drives the antenna panel to oscillate slowly around the expected satellite azimuth.

The sign inverter block **31** either passes with no change the signal from RF detector **6** or inverts its polarity, which is synchronized with the sine signal, produced by azimuth scanning block **25** in such a way, that the signal polarity of RF detector **6** is inverted when the sine signal is negative, or it is passed with no change when the sine signal is positive. The resultant signal at the output of sign inverter block **31** is integrated by integrator **37** for one sine period for the signal of azimuth scanning block **25**. At the end of sine period the result of integrating is stored in the memory **38** and the value of integrator **37** is reset. The result, stored in memory **38** is used as an azimuth error in orientation of the antenna panel ε_φ. It is scaled by some coefficient in the scaling block **20** and is added to azimuth angular velocity ω_φ.

The beam selection block **28** determines the two beams, which are closest to estimated elevation angle θ. The beam, which has a minimum distance to estimated elevation angle θ is considered as main beam, while the other – as secondary beam. The beam selection block **28** issues commands to the block for electronic beam control **5**, so that the main beam is selected for a long period, while the

secondary beam is selected for a short time, sufficient to measure the signal strength in its direction. The beam selection block **28** synchronizes the switch **29** with beam switching, so that the signal strength of the main beam is stored in the first beam memory **32**, while the signal strength of the secondary beam is stored in the second beam memory **33**. The values, stored in both beam memories **32** and **33** are used by the computation block **34** for calculation of the real elevation angle of the satellite toward the antenna panel θ_{RSSI}. The subtracting block **35** produces the difference between θ_{RSSI} and obtained by gyroscope measurements elevation angle θ, thus giving as result the elevation error ε_θ. It is scaled by some coefficient in the scaling block **22** and is added to elevation angular velocity ω_θ.

Both errors are used by the block for reverse coordinate transformation **36**, which converts them into three components, respectively collinear to axes Ox, Oy and Oz of the Cartesian coordinate system $Oxyz$ (**Fig. 4**). Every one of them is processed by a corresponding sign detector (respectively **39, 41** and **43**), which gives a result of +1 if the corresponding component is positive or −1 in the case of negative component. The output values from three sign detectors **39, 41** and **43** are scaled in corresponding scaling blocks **40, 42** and **44**, which in result gives the corrections, which need to be applied to offsets of three gyroscopes ε_x, ε_y and ε_z. Every correction is subtracted by subtracting blocks, respectively **45, 46** and **47**, from the contents of offset memories, respectively **13, 15** and **17**. The results from the subtraction are stored back into the same offset memories.

The signal drop detector **30** checks the strength of received signal. When it drops by more than a specified threshold value, it clears ε_φ and ε_θ errors, to prevent changing of ω_{x0}, ω_{y0}, ω_{z0}, φ and θ due to the noise of detected signal during interruption of signal reception by some obstacle between antenna and satellite. In this case the antenna beam orientation is controlled only by gyroscope signals.

The described algorithm is able to calculate two independent error values ε_φ and ε_θ, based on measurements of the signal strength at different points around the estimated direction to the satellite. However, in the reverse coordinate transformation there is no single solution for the corrections ε_x, ε_y and ε_z of three particular gyroscopes **1a**, **1b** and **1c**. To resolve this ambiguity additional corrections of offsets of gyroscopes **1a 1b**, which axes are close to the horizontal plane, are applied.

One variant of such correction, which does not use an additional sensor, is shown at **Fig. 6**. From output signal of one of gyroscopes **1a** the value ω_{xo}, stored in the offset memory **13 is subtracted**, which gives as a result the corrected signal ω'_x. It is further integrated by an integrator **49** for a period, determined by timer **50**. The sign detector **51** produces +1 as output signal when the result from integration is positive or −1 in the case of negative result. The resultant value is multiplied by a certain coefficient in scaling block **52** and at the end of integration period is fed by switch **53** to adder **54**, where it is added to the value, stored in offset memory **13**. The result of the addition is stored back into offset memory **13**. At the end of integration period the timer **50** resets the value of integrator **49**. As a result of described actions the stored offset value ω_{xo} is updated in up or down direction until the number of periods with positive value at integrator output becomes equal to the number of periods with negative value. The same actions are applied for gyroscope **1b**.

Another variant of correction of offsets of gyroscopes **1a** and **1b**, which axes are close to the horizontal plane, using inclinometers, is shown at **Fig. 7**. From output signal of one of gyroscopes **1a** the value ω_{xo} is subtracted, stored in the offset memory **13**, which gives as a result the corrected signal ω'_x. Using coordinate transformation, performed by block **56** the signal is converted in angular velocity, which vector is collinear to the sense axis of inclinometer **2b**, which

measures the inclination of axis Oy towards the horizontal plane. Further, the converted angular velocity is integrated by integrator **60**. The result from integration is compared in subtracting block **61** with the signal from inclinometer **2b**. The difference value is multiplied by certain coefficients in scaling blocks **59** and **62**. The result from scaling block **59** is used for correction of the result from the coordinate transformation in block **56** by adder **58**, while the result from scaling block **62** is subtracted from the value, stored in offset memory **13** by subtracting block **63**.

The same procedure is applied to the signal of gyroscope **1b**. From its output signal the value ω_{yo} is subtracted, stored in the offset memory **15**, which gives as a result the corrected signal ω'_y. Using coordinate transformation, performed by block **65**, the signal is converted in angular velocity, which vector is collinear to the sense axis of inclinometer **2a**, which measures the inclination of axis Ox toward horizontal plane. Further, the converted angular velocity is integrated by integrator **57**. The result from integration is compared in subtracting block **68** with the signal from inclinometer **2a**. The difference value is multiplied by certain coefficients in scaling blocks **67** and **69**. The result from scaling block **67** is used for correction of the result from the coordinate transformation in block **65** by adder **66**, while the result from scaling block **69** is subtracted from the value, stored in offset memory **15** by subtracting block **70**.